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Application of SCS-CN model in Runoff Estimation

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***Abstract**: The generation of runoff is triggered by the rain intensity and soil moisture status, and is calculated as the net precipitation times a runoff coefficient, which depends upon slope, land use and soil type. The runoff curve number (CN) is a key factor in determining runoff in the NCRS (National Resource Conservation Service) based hydrologic modeling method. The Soil Conservation Service Curve Number (SCS CN) also known as hydrologic soil group method is used in this study. The SCS CN is a quantative description of land use/land cover / soil complex characteristics of water shed. This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate result. From this study, hydrological forecasting will be done by using SCS CN modeling which can be further used for the management of water resources and land. The area selected for the present study consists of mainly river Amba (Catchment area of Pali and Tuksai) The result obtained will be useful for water management and irrigation scheduling of the study area.*
***Keywords**: NCRS (National Resource Conservation Service), curve number (CN), Pali and Tuksai catchment area, runoff estimation.*

I. INTRODUCTION

Water resources are essential renewable resources that are the basis for existence and development of a society. Proper utilization of these resources requires assessment and management of the quantity and quality of the water resources both spatially and temporally. Water crises caused by shortages, floods and diminishing water quality, among others, are increasing in all parts of the world. The growth of population demands for increased domestic water supplies and, at the same time, results with a higher consumption of water due to expansion in agriculture and industry. Mismanagement and lack of knowledge about existing water resources and the changing climatic conditions have consequences of an imbalance of supply and demand of water. The problem is pronounced in semi-arid and arid areas where the resources are limited. Surface water being easy, direct and therefore less expensive to exploit in comparison to other sources like groundwater or desalinization makes it the major source of water supply for irrigation, industry and domestic uses. The surface water, in the form of lakes and river discharge (runoff) is predominately obtained from rainfall after being generated by the rainfall runoff processes. In order to make decisions for planning, design and control of water resource systems, long runoff series are required. The latter are not often available with reasonable length. On the other hand, for flood control and reservoir regulation future, flows shall be forecasted with rainfall runoff models. A number of rainfall runoff models exist for generation of flow, forecasting and other purposes. Establishing a rainfall-runoff relationship is the central focus of hydrological modelling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations. As the computing capabilities are increasing, the use of these models to simulate a catchment became a standard. Models are generally used as utility in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, deforestation and other hydraulic structure such as dams and reservoirs. The conventional hydrologic data are inadequate for purpose of design and operation of water resources systems. Surface water runoff is a step in the water cycle on Earth. When precipitation occurs, water only has a few locations where it can go. Water can infiltrate into the ground, evaporate, or become runoff. Runoff is the short way of saying surface water runoff. Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. Estimation of the same is required in order to determine and forecast its effects. The problem of estimating runoff from a storm event is one of the key points in hydrologic modeling. Estimation of Direct rainfall runoff is always efficient but is not possible for most of the location at desired time. Classical techniques as the rational method or the Soil Conservation Service curve number approach are still widely used in practice. Due to the complexity of the hydrological processes and the basin characteristics, physically based distributed models using GIS and Remote sensing techniques are becoming popular. Use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall. In this paper, modified Soil conservation System (SCS) CN model is used for rainfall runoff estimation that considers parameter like slope, vegetation cover, area of watershed.

II. STUDY AREA

The entire Amba river system flows through the state of Maharashtra in Raigad and Pune districts. The Amba sub-basin falls in Western Ghats. Total length of Amba river is 78.179 Kms. The Amba sub basin has a tropical climate. The weighted average rainfall is more than 3157 mm. The mean July temperature varying between 20 °C and 34 °C and mean January temperatures are between 18 °C and 30 °C. The Sub basin falls into single major agro-climatic zone. Major part of the sub basin i.e. 31.73. % is covered with agricultural crops. Approximately 28.08% of the sub basin area is covered by forest; Wasteland covers around 21.89% of the total basin area. The important soil types found in the basin are medium black soils, , lateritic soils, alluvium, mixed soils (red and black, red and yellow, etc.) and saline and alkaline soils. The Catchment area for Tuksai is 44.31 km^2 and for Pali it is 329.3 km^2 Basin originates near at Rajmachi in Borghat., Tal. Maval, Dist. Pune. The catchment of the sub basin lies approximately between northern latitudes 18^0 45' and 18^0 86' and eastern longitude 73^0 21' and 72^0 92'. Hydrological data was obtained from the the department of State Data Storage Center Hydrology Project (Surface Water) Jal Vidnyan Bhavan, Dindori Road, Nashik. Land use pattern, soil information, geographical area of both catchment was take from Draft Report on ntegrated State Water Plan For Amba Valley by Government of Maharashtra.

III. SCS-CN METHOD OF MEASURING RUNOFF

The SCS curve number method is a simple method used on large scale for determination of the approximate runoff value corresponding to a certain rainfall quantity in a certain area. Although the method is designed for a single storm, it can be scaled to calculate the annual values for runoff in an area.

The runoff curve number (also called a curve number or simply CN) is an empirical parameter corresponding to different soil-vegetation-land use combinations. The SCS Curve number method only forecasts the quantity of runoff formed in any point of the catchment but does not model the flow routing or the distribution of runoff through time. Because of this reason the requirements of the method are quite low, only the rainfall depth and an empirical parameter named the Curve Number are mandatory. The Curve Number (CN) value can be obtained from the hydrologic soil group, land use and moisture conditions of the soil, the last two values being more important.

The SCS-CN method is based on the water balance equation and two fundamental hypotheses

The water balance equation states that:

$$P = Ia + F + Q \qquad \text{(i)}$$

The first hypothesis states that the ratio of the actual amount of direct runoff to the maximum potential runoff is equal to the ratio of the amount of actual infiltration to the amount of the potential maximum retention:

$$\frac{Q}{P-Ia} = \frac{F}{S} \qquad \text{(ii)}$$

The second hypothesis states that the amount of initial abstraction is some fraction of the potential maximum retention.

$$Ia = \lambda S \qquad \text{(iii)}$$

Where:

P = total precipitation (mm) ;

Ia = initial abstraction (mm);

F = cumulative infiltration excluding Ia (mm);

Q = direct runoff (mm);

S = potential maximum retention or infiltration;

The current version of the SCS-CN method presented in NEH4 considers λ equal 0.2 for the usual practical applications. As the initial abstraction component accounts for factors like surface storage, interception and infiltration before runoff begins, λ can also take other values depending on the application. In theory, λ can take any value between 0 and ∞ but most of the current applications use the suggested value of 0.2.

Combining equations (1.2) and (1.3), the main equations for the SCS Curve Number Method are obtained:

$$Q = \frac{(P-Ia)^2}{(P-Ia+S)} \qquad \text{(iv)}$$

$$Ia = 0.2 \text{ x } S \qquad \text{(v)}$$

By replacing Ia in equation (1.1), an equation with only two parameters is obtained.

$$Q = \frac{(P-0.2\,xS)^2}{(P-+0.8\,S)} \qquad \text{(vi)}$$

The potential maximum soil retention, S, can be obtained according to the CN value.

$$S = \frac{25400}{CN} - 254 \qquad \text{(vii)}$$

The equations are based on the trends observed in data obtained from the study areas, so they are empirical equations rather than equations based on physical laws. The CN is a Hydrologic parameter that relies implicitly on the assumptions of extreme runoff events and Represents a convenient representation of the potential maximum soil retention,.

A. Soils

In determining the CN, the hydrological classification is adopted. Here soils are classified into four classes A, B, C and D based on the infiltration and other characteristics. The important soil characteristics that influence the hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and the permeability. Following is a brief description of four hydrologic soil groups:

1) *Group a (low runoff potential):* Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sand or gravels. These soils have high rate of water transmission.
2) *Group b (moderately low runoff potential):* Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.
3) *Group c (moderately high runoff potential):* Soils having low infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.
4) *Group D (High Runoff Potential):* Soils having low infiltration rates when thoroughly wetted and consisting chiefly of clay soils with high swelling potential, soil with permanent high water table, soils with clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

B. Antecedent Moisture Condition (AMC)

AMC refers to the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial abstraction and infiltration and are governed by AMC. For purposes of practical application three level of AMC are recognized by SCS as follows

1) *AMC-I:* Soils are dry but not to wilting point. Satisfactory cultivation has taken place.
2) *AMC-II:* Average conditions
3) *AMC-III:* Sufficient rainfall has occurred within the immediate past five days. Saturated soil conditions prevail.

The Curve Number (CN) is used in the determination of S and values for the CN for different landuse, soil types and soil moisture conditions can be found in tables (table 1).

Table 1. CN no. for different Soil Conditions [8]

Land use	Cover		Hydrologic Soil Group			
	Treatment or practice	Hydrologic condition	A	B	C	D
Cultivated	Straight row		76	86	90	96
Cultivated	Contoured	Poor	70	79	84	87
		Good	65	75	82	86
Cultivated	Contoured and terraced	Poor	66	74	80	83
		Good	62	71	77	82
Cultivated	Bunded	Poor	67	75	81	82
		Good	59	69	76	79
Cultivated	Paddy		95	95	95	95
Orchards	With understory cover		39	53	67	72

	Without understory cover		41	45	69	75
Forests	Dense		26	40	52	65
	Open		28	44	60	67
	Scrub		33	47	60	69
Pastures	Poor		68	79	86	88
	Fair		49	69	79	85
	Good		39	61	74	83
Wasteland			71	80	85	89
Roads (dirt)			73	83	88	91
Hard surface areas			77	86	91	95

IV. METHODOLGY

The SCS-CN Model was applied on the Catchment Area of Tuksai and Pali Respectively having area 44.31 km2 ,329.3 km2. For Tuksai, Rainfall Data from year 1994-1996(3 years) was considered for calibration and year 1997(1 year) was used for validation. For Pali, Rainfall Data from year 1994-1997(4 years) was considered for calibration and year 1998(1 year) was used for validation. The Nash-Sutcliffe efficiency (NSE) was used to assess the SCS-CN model performance.

A. Formulation of the model

This model adopts various flow paths in stream flow generation, such as (1) Surface runoff (2) Through flow and (3) Base flow; along with rainfall dependent initial abstraction

This algorithm operates on daily time basis and, therefore, requires daily data of rainfall and evaporation as input to explain the physical behaviour of the catchment. The observed runoff is used for model evaluation.

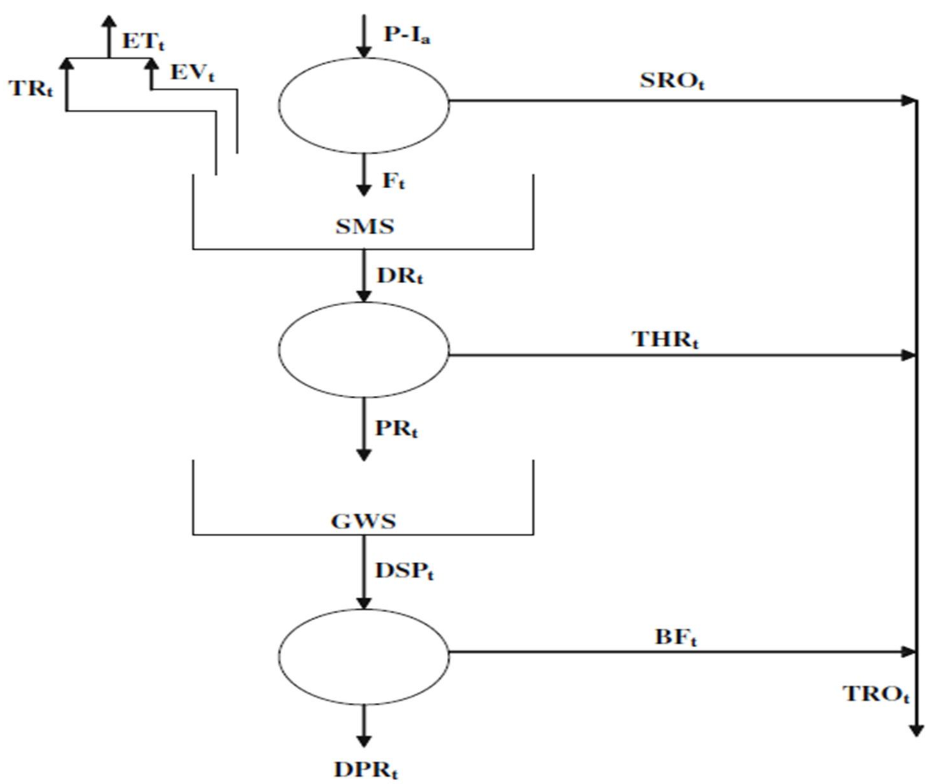

Fig. 1. Schematic diagram of SCS-CN-based rainfall-runoff model [1]

B. Initial Abstraction

The initial abstraction Ia is taken as a fraction of the possible retention in the soil and is computed as:

$Ia(t) = \lambda\ S(t)$, if $t \leq 5$ days (viii)

Here, λ is the parameter to be optimised. Ia(t) and St are the daily initial abstraction and daily potential maximum water retention.

C. Routing of Rainfall Excess

When the number of days exceeds 5, to transform the surface runoff that is produced at the outlet of the basin, ROt (10) is routed using a single linear reservoir concept, as in (14). Then ROt is routed to the outlet of the basin using the single linear reservoir as below.

SROt = Do X ROt + D1 X ROt-1 + D2 X SROt-1 (ix)

Where,

Do = ((1/K))/(2+(1/K))

D1 = Do

D2 = (1+(1/K))/(2 +(1/K))

Here, SROt is the routed surface runoff at the outlet of the catchment and K is the storage coefficient.

D. Infiltration

This amount of water reaching the ground after Ia and not produced as surface runoff is assumed to infiltrate into the upper soil. Ft-1 is the previous day infiltration (mm) computed using water balance equation

F(t-1) = P(t-1) – Ia(t-1) - RO (t-1) (x)

Here, if $Pe(t) \geq 0$, $Ft \geq 0$.

E. Evaporation

The daily evaporation EVt is computed as follows :

EVt = PANC X EVPt (xi)

Where EVPt is the potential evaporation based on the field data and PANC is the Penmann coefficient, assumed as 0.8 for June-September and 0.6 for October-November, and 0.7 for February-May.

F. Base Flow

The base flow of a watershed is the ground water release from a catchment in a stream. This active ground water flow which is also known as delayed flow can be modeled as outflow from a non-linear storage in the form of base flow (BFt)

BFt = bf X F (xii)

Where bf = ground water zone runoff coefficient.

G. Total Stream Flow

The total stream flow (TROt) on a day 't' is obtained as the sum of the above three components, surface runoff, throughflow, and base flow . if $t \leq 5$days,

TRO = ROt + BFt (xiii)

and if t> 5 days,

TROt = SROt + BFt (xiv)

V. RESULT AND DISCUSSION

The SCS-CN model used the antecedent moisture factor with the effect of antecedent rainfall to estimate the daily water retention store and then the water retention store gets updated by taking into account of daily evapotranspiration, drainage from soil moisture store and infiltration to the soil moisture store. The optimal estimates of model parameters were obtained by trial-and-error. Table 1 shows the ranges and initial estimate of each parameter and also the optimised values of the parameters involved in the model formulation.

Table 2. Estimates of Parameters and EFFICIENCY of the Model

Sl no.	Parameters	Range	Optimised Values	
			Pali	Tuksai
1	Area		329.3 km^2	44.31 km^2
2	CN	0-100	39	39
3	λ	0-1.00	0.2	0.2
4	bf	0-1.00	0.05	0.55
5	K	0-5.00	0.9	1
6	Efficiency (Calibration)		47.50%	52.60%
7	Efficiency (Validation)		88%	72%
8	Runoff Factor		0.73	0.73

Table 3. Annual Rainfall, Observed Runoff, Simulated Runoff and Relative Error for Model Using Annual Data (Pali)

Sl. No.	Year	Rainfall(mm)	Obseved Runoff(mm)	Simulated Runoff(mm)	Relative Error(%)
Pali					
1	1994	3861.9	2733.3	3088.64	-10.15
2	1995	2439.5	1042.66	1522.29	-46
3	1996	3083	1712.33	2242.62	-30.96
4	1997	3145.2	1137.52	2287.61	-101
5	1998	3743.1	2716.29	2922.3	-5.91
Average		3254.54	1868.42	2412.692	-38.804

Table 4. Annual Rainfall, Observed Runoff, Simulated Runoff and Relative Error for Model Using Annual Data (Tuksai)

Sl. No.	Year	Rainfall(mm)	Obseved Runoff(mm)	Simulated Runoff(mm)	Relative Error(%)
Tuksai					
1	1994	4079.2	3293.6	3329.47	-1.08
2	1995	3033.5	1375.56	2108.47	-53.28
3	1996	3246.46	1896.42	2410	-27.07
4	1997	2865.3	2348.3	2014.43	15.12
Average		3306.115	2228.47	2465.5925	-16.5775

The model yields average efficiency of 47.5 % and 88 % in calibration and Validation Respectively in Pali catchment whereas Tuksai Catchment Produces the efficiencies of 52.6% and 72 % in calibration and Validation Respectively. The Average relative Error in Pali catchment area is -38.84 whereas Tuksai catchment has Relative error of -16.57. The R.E. – values indicating negative values imply the model over estimates the runoff values. The least Deviation in RE values are seen in 1998 in Pali catchment i.e. -5.91% during validation Whereas in tuksai catchment RE of -1.08% is observed in Calibration in 1994.

VI. CONCLUSIONS

The present study has been carried out to assess the surface runoff. This model gives quick estimate of generated runoff in a particular location with reasonably good accuracy. The Predictions are found to be lower than actual observe direct runoff of the catchment. Inaccuracy of the input data may lead to improper outcome of the model as lots of parameters are involved in the model.

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